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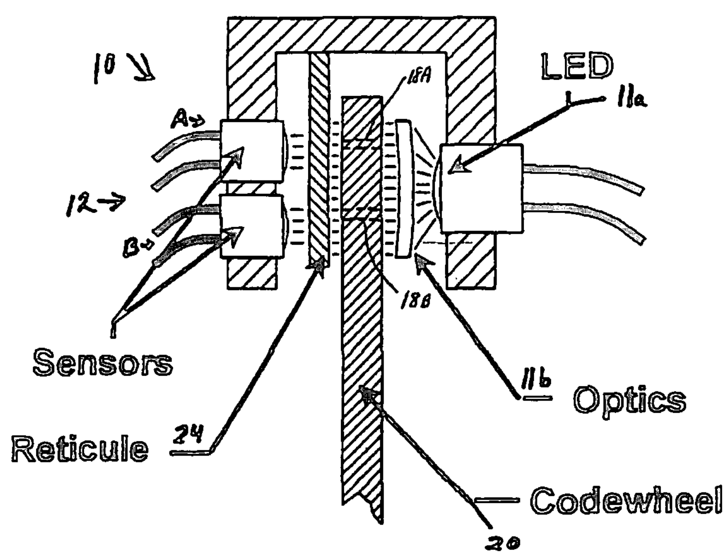
(54) Title: INCREMENTAL OPTICAL ENCODER



(57) Abstract: An incremental optical encoder (10) for measuring angle of rotation or linear displacement of a movable member and for determining the direction of such movements comprises a light source (11a) emitting a light beam along an optical path, an encoder plate (20), secured to the movable member, provided with a series of opaque zones and light transmissive zones (18A, 18B) arranged so as to cross the optical path and to modulate the light beam upon movement of the encoder plate, and a plurality of light detectors (A, B) arranged for generating output signals in quadrature upon movement of the encoder plate. The light detectors are arranged in separated and inter-digitated detector arrays and in at least two channels. A reticule (24) is located between the detectors and the encoder plate, and a detent structure establishes a gap between the reticule and the encoder plate.

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For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

INCREMENTAL OPTICAL ENCODER

Cross Reference To A Related Application

Applicants claim priority based on Provisional Application No. 60/152,274 filed September 3, 1999 entitled "Incremental Optical Encoder", which is incorporated herein by reference.

Background Of The Invention

This invention relates to incremental optical encoder devices for measuring an angle of rotation or a linear displacement of a movable member as a function of time and for determining the direction of such movements.

Known devices for measuring the angle of rotation of a rotating member comprise, for example, a light source, a disc which is secured to the rotating member and is arranged for producing a modulation of light by means of windows, *i.e.*, by zones which allow passage of the light through them alternating the opaque zones, a mask arranged close to the disc also provided with light transmissive zones and opaque zones, and a detection device including light detectors. By placing the mask corresponding to the different light detectors according to an appropriate pattern, output signals in quadrature are produced the frequency of which corresponds to the number of alternations of opaque zones and of light transmissive zones.

Summary Of The Invention

The present invention provides a new and improved incremental optical encoder characterized by

improvements in gap setting, mounting, detector configuration and the illumination source.

The following detailed description of the invention, when read in conjunction with the accompanying drawing, is in such full, clear, concise and exact terms as to enable any person skilled in the art to which it pertains, or with which it is most nearly connected, to make and use the invention. The advantages and characterizing features of the present invention will become clearly apparent upon a reading of the following detailed description together with the accompanying drawing.

Brief Description Of The Drawing Figures

Fig. 1A is a diagrammatic view of a basic incremental optical encoder;

Fig. 1B is a diagrammatic view illustrating operation of the encoder of Fig. 1A;

Fig. 1C is a graph including waveforms illustrating operation of the encoder of Fig. 1A;

Fig. 2 is a perspective view, with parts broken away, of a basic optical encoder;

Fig. 3 is a developed view of a basic incremental optical encoder;

Fig. 4 is a developed view illustrating installation of a basic incremental optical encoder;

Figs. 5A and 5B are elevational views, partly in section, illustrating mounting of a basic incremental optical encoder on a motor;

Fig 6A is a schematic diagram of a prior art detector device;

Fig. 6B is a schematic diagram illustrating a detector arrangement in a basic incremental optical encoder;

Fib. 7 is a schematic diagram illustrating the detector layout in a basic incremental optical encoder;

Fig. 8 is a schematic diagram illustrating an inter-digitated photodiode detector array in a basic incremental optical encoder;

Figs. 9 and 10 are schematic diagrams illustrating the detector array in the incremental optical encoder of the present invention;

Figs. 11A and 11B are developed perspective views illustrating the gap setting procedure in the incremental optical encoder of the present invention;

Figs. 11C and 11D are fragmentary elevational views further illustrating the procedure of Figs. 11A and 11B;

Figs. 12A and 12B are developed perspective views illustrating another form of gap setting procedure according to the present invention;

Figs. 12C and 12D are fragmentary elevational views further illustrating the procedure of Figs. 12A and 12B;

Figs. 13 - 16 are schematic diagrams further illustrating the detector array in the incremental optical encoder of the present invention;

Figs. 17 - 21 are arrangements of elevational, sectional and perspective views illustrating the adaptable mounting plates in the incremental optical encoder of the present invention;

Figs. 22A and 22B are elevational and sectional views, respectively, of the illumination source in the incremental optical encoder of the present invention;

Figs. 23A -23D are views further illustrating the incremental optical encoder of the present invention;

Figs. 24A - 24D are views further illustrating the adaptable mounting plates in the incremental optical encoder of the present invention; and

Fig. 25 is a graph including waveforms illustrating operation of the incremental optical encoder of the present invention.

Detailed Description Of The Illustrated Embodiments

Fig. 1A shows an optical encoder 10 of the prior art which comprises a light source 11a and a lens 11b delivering a beam of light which is directed toward a detection device 12. Device 12 comprises a plurality of sensors, two of which are designated A and B in Fig. 1 and which represent separate detector channels as will be described. The light of each light channel which impinges onto a corresponding light detector is modulated by slots 18A, 18B of a rotatable encoding disc or codewheel 20 in association with a mask or reticule 24 which has openings therein as known. The disc 20 is secured to a member (not shown) which rotates about the same axis as the disc 20 and of which it is desired to obtain information relating to its rotation.

The principle of modulation for an encoder like that shown in Fig. 1A is illustrated in Fig. 1B for a pair of light detectors A and $\bar{A}$, each being respectively associated to a corresponding light channel. A similar representation can be made for corresponding light detectors B and $\bar{B}$ or for any other channel. Rotation of disc 20 having slots or windows 18 and opaque bars 19, with respect to the stationary mask 24 results in a cyclical modulation of the light impinging onto the light detectors A and $\bar{A}$. Thus the light detectors will deliver signals A and $\bar{A}$ as a function of the angle of rotation α in accordance with the graph of Fig. 1C. The

arrangement is such that the modulation of light received by the light detector A is in opposite phase to the modulation of light received by the light detector $\bar{A}$. The same principle applies to the light detectors B and $\bar{B}$, so that the signals A, B, $\bar{A}$, $\bar{B}$ are in quadrature, in other words, they are identically shaped and are 90° out of phase with each other. In the case of high resolution encoders, the mutual positioning of the disc 20, the mask 24 and the light detectors of the detection device 12 is a delicate operation.

For a more detailed description of incremental optical encoders heretofore available, reference may be made to published Swiss patent application 577/95 of March 1, 1995 or its French counterpart 08/609,988 of February 29, 1996, both entitled "Incremental Optical Encoder Device", the disclosures of which are hereby incorporated by reference.

A first improved feature in the incremental optical encoder of the present invention is the provision of non-contact gap setting. The most critical processes in the installation of an optical encoder (which is usually mounted on the rear end of a motor) are the concentric alignment of the codewheel and reticule ("centering") and the correct setting of the distance between the codewheel and reticule ("gapping'). Figs. 2 and 3 show the basic elements involved and their arrangement in a basic incremental optical encoder. Figs. 4 and 5 illustrate the centering and gapping process used on the basic incremental optical encoder of Figs. 1-3. In particular, an incremental optical encoder 10' of the type shown in Fig. 1 is illustrated in Fig. 2 contained within a housing 40. The exploded view of Fig. 3 shows the device of Fig. 2 including housing component 42 which contains the mask and the optical sensors (not

shown) and from which a flexible printed circuit 44 with connector 46 extend, codewheel 48, base plate 50, LED light source 52 and housing component 54. Figs. 4, 5A and 5B illustrate the steps of placing an adapter plate 60 onto motor 62, installing a centering tool 64 on the motor shaft 66 and centering the adapter plate 60, installing mounting screws 70, positioning encoder 10′ on adapter plate 60 with a gapping shim 72 installed, tightening the hub set screw with an Allen wrench 74 and removing the gapping shim 72 and twist locking encoder 10′ in place.

While the procedure illustrated in Figs. 1-5 is typical of state-of-the-art modular encoders and represents a substantial improvement over processes used in earlier generations of such devices, a further simplification has been developed in the incremental optical encoder of the present invention.

In accordance with the present invention, a base, which mounts to the motor end-bell, is still required, as is a small tool to center the plate about the motor shaft while the fastening screws are being inserted. However, a gapping shim is not needed and the procedure is non-contacting with respect to the codewheel. The encoder module is placed on the mounting base and is twisted (rotated) to engage a designed detent position. At this angular location, the axial position of the codewheel is correctly located and an Allen key is used to tighten the setscrew which fastens the hub of the codewheel to the motor shaft. Subsequently, a further rotation of the encoder module locks the body in position and ensures that the reticule to codewheel gap is correct for optimum optical functioning. Thus, the installation process is simplified and improved since the skill involved in using the gapping shim correctly

is eliminated. The foregoing is illustrated in Figs. 11 and 12.

In particular, and referring to Figs. 11A-D, an encoder adapter 80 is placed onto the rear end plate 82 of motor 84 and a centering tool 86 is installed on the motor shaft 88 to center adapter 80 with respect to shaft 88. Adapter 80 is secured to motor rear end plate 84 by fasteners 90 and centering tool 86 is removed. The encoder assembly 92 is positioned and mounted on adapter 80 by means of angularly spaced bayonet snaps on encoder 92 received in corresponding slots in adapter 80. When encoder 92 is in full counterclockwise direction on legs of adapter 80, the gapping position #1 shown in Fig. 11C is attained. A hex wrench 100 is employed to tighten the codewheel set screw while the codewheel is pushed down. Then the encoder 92 is pushed down and rotated 30° clockwise to lock it in place at position #2 shown in Fig. 11D. Cover 102 is aligned with encoder 92 and snapped into position.

The procedure illustrated in Fig. 12 adapts the foregoing to commutation encoder installation. The procedure in Fig. 12A is similar to the procedure in Fig. 11A. Referring to Fig. 12B, motor 84′ is energized to hold shaft 88′ at zero degrees by applying a positive voltage to the W motor winding <u>and</u> a negative voltage to the V motor winding. The U motor winding is not connected. The encoder hub set screw 110 is aligned with the encoder Z signal and the U signal rising transition. The encoder hub set screw 110 is aligned with the LED on the encoder PCB as shown in Fig. 12B. These positions are the leading edges (CCW at encoder end) of encoder commutation signal U at the encoder position detector. Once installed, the encoder signal U will be in transition, U will be low and W will be high.

The encoder hub 112 is seated against the encoder housing by pressing slightly on the hub 112 and tightening hub set screw 110. Three servo cleats are installed on the encoder perimeter. The cleats are temporarily tightened and the encoder 92′ is twisted clockwise into adapter 80′. The cleats are loosened enough to rotate encoder 92′ for alignment.

Next, the encoder commutation tracks are aligned with the motor windings within 1.5 mechanical degrees. With the motor 84′ still energized as described above, the commutation tracks are aligned when a slight twisting of the motor shaft 88′ in one direction will cause the U encoder signal to transition high and a slight twist of the motor shaft in the opposite direction will cause U to transition low. When the motor shaft 88′ is released after twisting, U should remain in its high or low state and not transition to the opposite state. The encoder 84′ may be rotated around the motor shaft if repositioning is required for alignment. No more than 5 or 10° rotation should be required. The servo cleats are tightened to hold the encoder in place. The encoder commutation track U is now aligned with the motor windings as set forth in Table 1.

Table 1

Encoder Signal In Response To Motor Shaft Angle

Motor (cw) Shaft Angle	Encoder Signal U	Encoder Signal V	Encoder Signal W
0°	X	L	H

30°	H	L	X
60°	H	X	L
90°	X	H	L
120°	L	H	X
150°	L	X	H

H=High L=Low X=Transition

The tracks V and W are checked by energizing the motor 84′ shaft angles at 60° and 120 per table 1 and repeating the dithering procedure described hereinabove.

A second improved feature in the incremental optical encoder of the present invention is the provision of adaptable mounting plates. Current modular encoders employ a base or adapter plate as shown in Fig. 4 for attachment of the unit to the end-bell of the motor. If the bolt pattern of the motor does not match that of the encoder base plate, then a custom aluminum plate is needed as an intermediary to facilitate mounting. In the incremental optical encoders according to the present invention, the base plate is adaptable in the sense that suitable mounting bases are available for the major lines of servomotors. Once a base plate is available for a given motor, all other components and mounting operations are common ~~to~~ all motor types. This is illustrated in Figs. 16-20. In other words, while it is conventional to have one bolt pattern per mounting plate, in the arrangement shown in Figs. 17-21 a single mounting plate has multiple mounting hole patterns.

In particular, the base or adapter plate 130 shown in Figs. 17A-17D has a particular pattern of holes 132, 134 for bolts angularly located relative to hub 135 along with bayonett snaps 136, 138 and 140. The base or

adapter plate 144 shown in Figs. 18A-18D has only the pattern of bayonett snaps 146, 148 and 150 angularly located relative to hub 152. The base or adapter plate 154 of Figs. 19A-19D has a more complex pattern angularly located relative to hub 156. In particular, there are two outer bolt holes 158 and 160 and three bayonett snaps 162, 164 and 168 near the periphery of plate 154. In addition, there is an inner arrangement of two larger diameter bolt holes 170, 172 and three smaller diameter bolt holes 174, 176 and 178 located around hub 156. Thus, adapter plate 154 of Figs. 19A-19D combines the bolt hole and bayonett patterns of adapters 130 and 144 of Figs. 17 and 18 to accommodate several different motor connection patterns. The base or adapter plate 180 shown in Figs. 20A-20D has bolt holes 182, 184 along with bayonett snaps 186, 188 and 190 angularly located relative to hub 192 and, in addition, a notch formation 194 at a particular angular location around plate 180 relative to the other structures. The base or adapter plate 200 shown in Figs. 21A-21D includes bayonett snaps 202, 204 and 206 angularly located relative to hub 208 and of a height greater than those shown in Figs. 17-20.

Thus, the mounting plate structures, i.e. bolt holes, bayonett snaps, notches to facilitate connection of encoder to motor are selected to accommodate a range of motors, such as in adapter plate 154 of Fig. 19 and adapter plate 180 of Fig 20. This is illustrated further by the adapters of Figs 24A-24D which accommodate mounting patterns normally requiring a number of different adapters.

A third improved feature in the incremental optical encoder of the present invention is the provision of separated, inter-digitated diode detector arrays.

Incremental optical encoders have two primary digital signal channels; A and B. The digital signals are synthesized from analog signals that are generated by photodiode detectors co-operating with the illumination and optics of the encoder. In practice, it is well-recognized that better performance is obtained by generating complementary analog signals (A and A-, B and B-) from twice the number of photodiode detectors.

The present state-of-the-art in modular encoders is to integrate multiple photodiode detectors, per analog signal channel, onto an application-specific integrated circuit (ASIC). Fig. 6 illustrates the approach and describes the advantages that result. In particular, Fig. 6A schematically shows a detection device 220 arranged for deriving logical signals from the signals delivered by the light detectors which receive the light emanating from the light source of the device which has the form of a photodiode 222. The light detectors A and $\bar{A}$ are connected to a comparator 224, while the light detectors B and B are connected to a comparator 226, the comparators delivering corresponding logical signals. The logical signals are utilized by appropriate circuits in a manner readily understood by those skilled in the art.

The light-sensitive surfaces of the light detectors may have a rectangular shape so that they are easier to manufacture in the form of integrated circuits. Such a form 230, as shown in Fig. 6B, further makes it possible to use such light detectors on discs of different diameters and are advantageously used for linear optical encoders. In the case of rotatable disc, such as disc or codewheel 20, the dimensions of the rectangular metallized zones can be adapted so as to take into account the curvature effect resulting from the use of

such a disc. Furthermore, the assembly of light-sensitive surfaces shown in Fig. 6B is in the form of a matrix. In Fig. 6B, the detection device comprises a first group 232 and a second group 234 of light detectors, each formed by four light detectors A, B, $\bar{A}$, $\bar{B}$. The signals generated by corresponding light detectors, i.e. light detectors identified by the same reference A, B, $\bar{A}$, $\bar{B}$ are added up in the encoder device. As will be seen from Fig. 6B, such corresponding light detectors of the first and second groups are arranged at different locations in a transverse direction so that any non-uniformity of light intensity over the cross-section of the light beam will be compensated. Similarly, Fig. 7 shows schematically a layout 240 of the detectors that is employed on the ASIC of a prior art encoder. A further known improvement is to employ inter-digitated arrays of photodiode detectors as shown in Fig. 8, the detectors of a given channel being connected via a bus line 242.

The incremental optical encoder of the present invention seeks to improve upon this arrangement in order to address certain specific limitations. The layout 250 according to the present invention is shown in Figs. 9 and 10. The principal idea involves separating the inter-digitation of the A and A- channels from that of the B and B- channels. Consequently, the following advantages accrue. First, the detector pitch (shown in Fig. 8) is limited by the semiconductor fabrication process of the photodiode detectors and heretofore has been about 40 microns at best. In turn, for a given diameter of codewheel, this leads to a limitation on the maximum possible line count and, therefore, resolution of the encoder. By separating the inter-digitation of the A/A- and B/B- arrays, according

to present invention, the maximum achievable resolution is doubled. Second, the magnitude of the modulation of the signals that results from the shuttering action of the codewheel and the recticle is increased, as is the signal-to-noise ratio. In addition, any phase shift between the A/A- and B/B- signals owing to illumination variations is lessened. Third, the spectral purity of the analog signals is improved and the differences in offset voltage levels are reduced. Consequently, the opportunities for using interpolation techniques to multiply the encoder resolution by electronic means are improved. Fourth, the modulation of the index channel signals is correspondingly increased.

The separated, inter-digitated diode detector arrays are illustrated further in Figs. 13-16. Fig. 13, in particular, shows the separation of the detector arrays for the A and B channels. In addition to the benefits listed hereinabove, the modulation of the index channel signals (Z and Z-) is increased. The unusual pattern of the index pulse arrays shown in Fig. 13 corresponds to a 500 line/revolution encoder layout. Thus, the A channel 252 contains A and A- detectors and the B channel 254 contains B and B- detectors. Index channels 256 and 258 correspond to index and index bar diode arrays Z and Z-, respectively. The commutation tracks 260, 262 and 264 are for $\overline{W}$, V and U, respectively along with commutation tracks 266, 268 and 270 for U-, V- and W-. Fig. 14 shows the index center point 274, and light metal mask shields 276 over the index inactive areas. For a given encoder resolution, the graph of Fig. 16 shows the appropriate pattern of the array for the index channel. These patterns were generated to determine the pattern which optimized the optical

contrast for the index signals at a given encoder resolution.

The basic idea is that the same pattern is placed on the detector array and on the encoder disc. Considering the Z signal, for example, as the disc pattern begins to traverse across the array on the detector, little optical flux is transmitted. However, in the position of alignment, the transmitted flux is maximized. The improvement contained here is that the transmitted flux remains low until alignment is reached; there is not a gradual increase in transmitted light over a wide angular distance. In fact, just prior to the position of alignment, the transmitted flux actually decreases. The net effect is that the generated index pulse is sharp and repeatable. Another feature of the patterns is that they generate index pulses that are symmetrical with respect to the direction of rotation of the encoder disk.

A fourth improved feature in the incremental optical encoder of the present invention is the provision of the illumination source 300 shown in Figs. 22A and 22B. Novel features of the illumination source include a surface-mounted, point-source IR LED die 302 and a glass aspheric lens 304, integrated on the LED, for collimation. This enables higher encoder resolutions and provides signal integrity during operation at an increased specification of maximum shaft end-play. The LED device is packaged in a hermetically sealed T046 package 306. The three features of point-source led, aspheric lens and hermetic packaging are combined together for the first time.

Figs. 23A-D show a completed and assembled encoder 320 incorporating the features of the present invention.

The waveforms of Fig. 25 further illustrate the operation of the encoder of the present invention.

It is therefore apparent that the present invention accomplished its intended objectives. While embodiments of the present invention have been described in detail that is done for the purpose of illustration, not limitation.

The Claims

1. An incremental optical encoder device for measuring an angle of rotation or a linear displacement of a movable member as a function of time and for determining the direction of such movements, comprising a light source emitting a light beam along an optical path, an encoder plate secured to said movable member and provided with a series of opaque zones and of light transmissive zones, said zones being arranged so as to cross said optical path and to modulate said light beam upon movement of said encoder plate, detection means to receive the modulated light beam for generating output signals upon movement of said encoder plate, a reticule arranged between the detection means and the encoder plate, and a detent structure for establishing a gap between the reticule and the encoder plate.

2. An incremental optical encoder device for measuring an angle of rotation or a linear displacement of a movable member as a function of time and for determining the direction of such movements, comprising a light source emitting a light beam along an optical path, an encoder plate secured to said movable member and provided with a series of opaque zones and of light transmissive zones, said zones being arranged so as to cross said optical path and to modulate said light beam upon movement of said encoder plate, detection means to receive the modulated light beam for generating output signals upon movement of said encoder plate, said movable member comprising a motor shaft, and an adapter for connecting said encoder device to a motor, said adapter having a pattern of connecting structures arranged to accommodate a plurality of different connecting structures present on different motors.

3. An incremental optical encoder device for measuring an angle of rotation or a linear displacement of a movable member as a function of time and for determining the direction of such movements, comprising a light source emitting a light beam along an optical path, an encoder plate secured to said movable member and provided with a series of opaque zones and of light transmissive zones, said zones being arranged so as to cross said optical path and to modulate said light beam upon movement of said encoder plate, and detection means including a plurality of light detectors, each detector having a light-sensitive surface arranged to receive the modulated light beam, said detection means being arranged for generating output signals in quadrature upon movement of said encoder plate, said light detectors being arranged in separated and inter-digitated detector arrays.

4. An incremental encoder device according to claim 3, wherein the detectors are arranged in at least two channels.

5. An incremental optical encoder device for measuring an angle of rotation or a linear displacement of a movable member as a function of time and for determining the direction of such movements, comprising a light source emitting a light beam along an optical path, an encoder plate secured to said movable member and provided with a series of opaque zones and of light transmissive zones, said zones being arranged so as to cross said optical path and to modulate said light beam upon movement of said encoder plate, and detection means to receive the modulated light beam, for generating output signals upon movement of said encoder plate, said light source comprising the combination of a point

source infrared light-emitting diode and an aspheric lens.

6. An incremental encoder device according to claim 5 wherein the light-emitting diode and aspheric lens are combined in an hemetically sealed package.

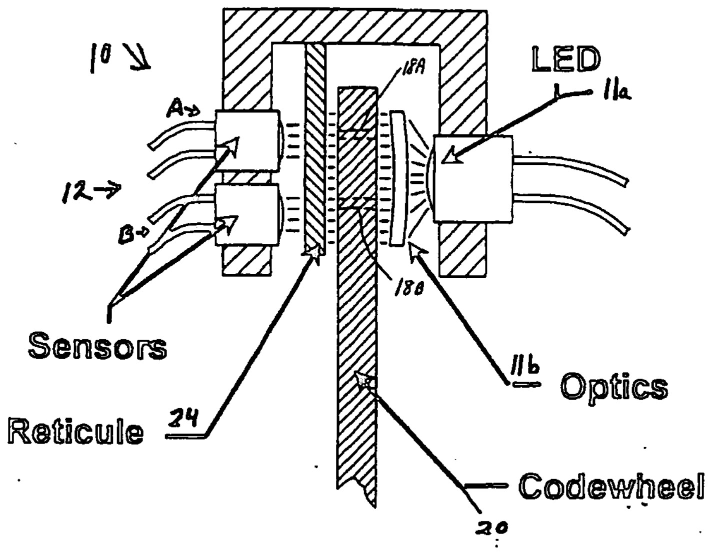
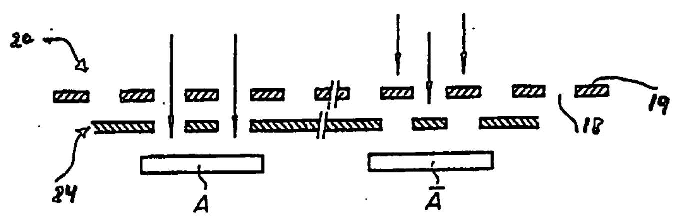


Fig. 1A



PRIOR ART

Fig. 1B

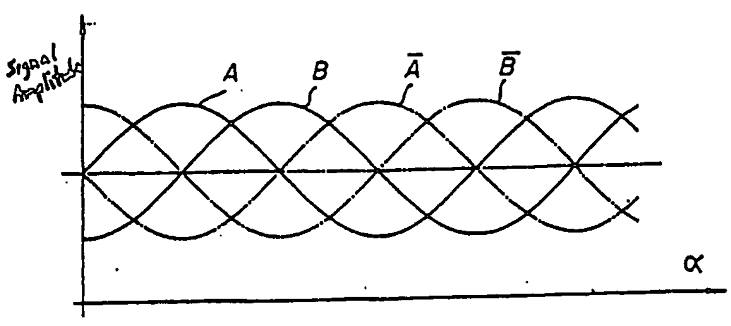


Fig. 1C

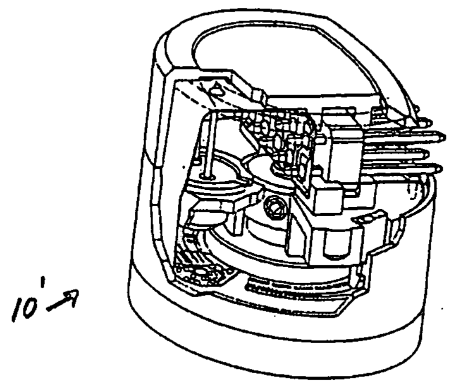


Fig. 2

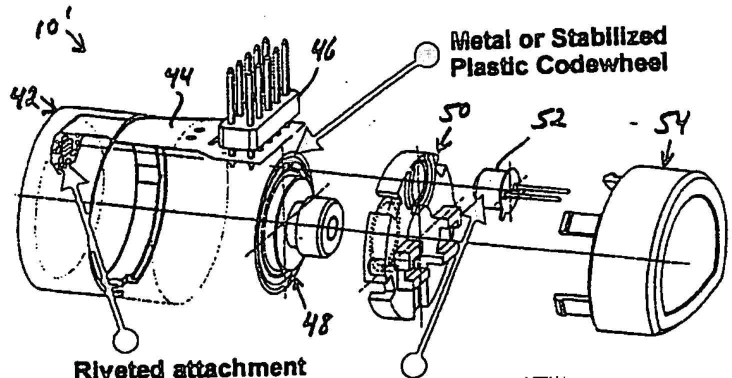


Fig. 3

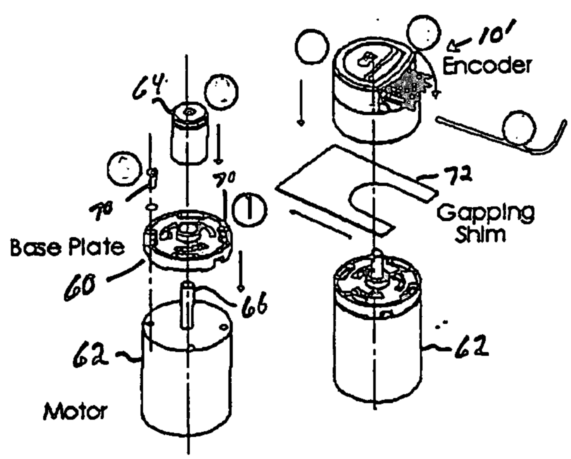


Fig. 4

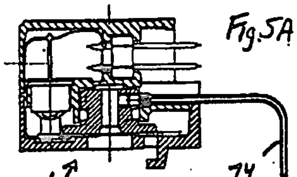


Fig. 5A

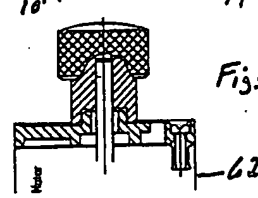


Fig. 5B

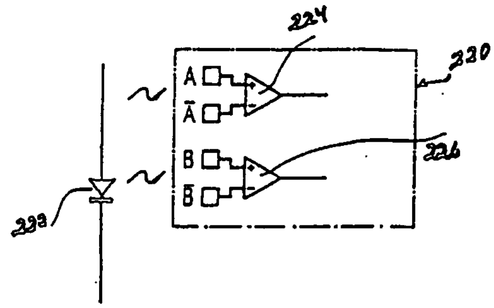


FIG 6A

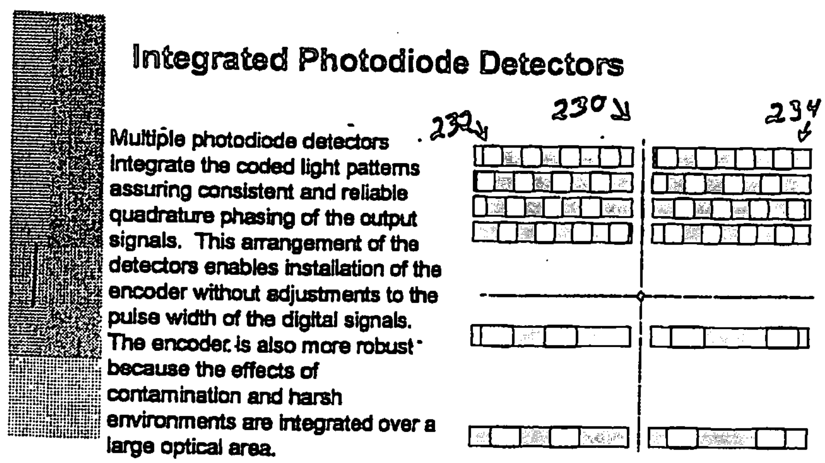


FIG. 6B

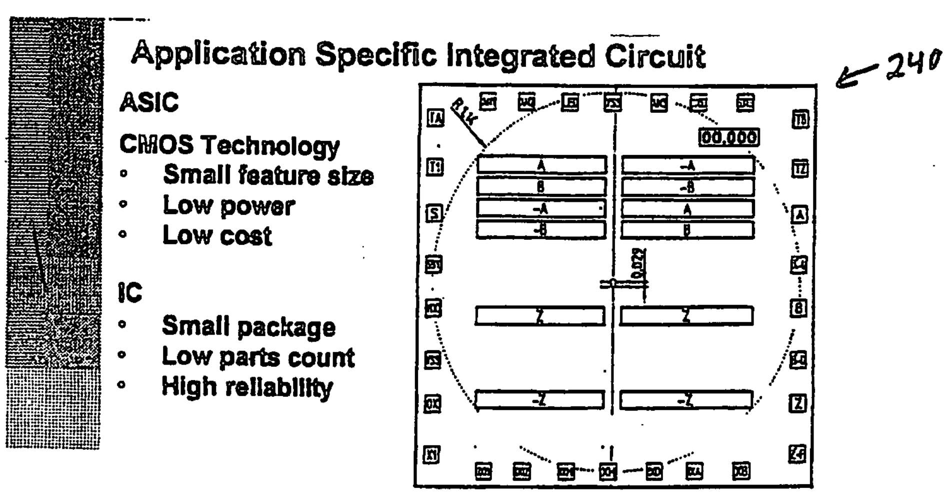
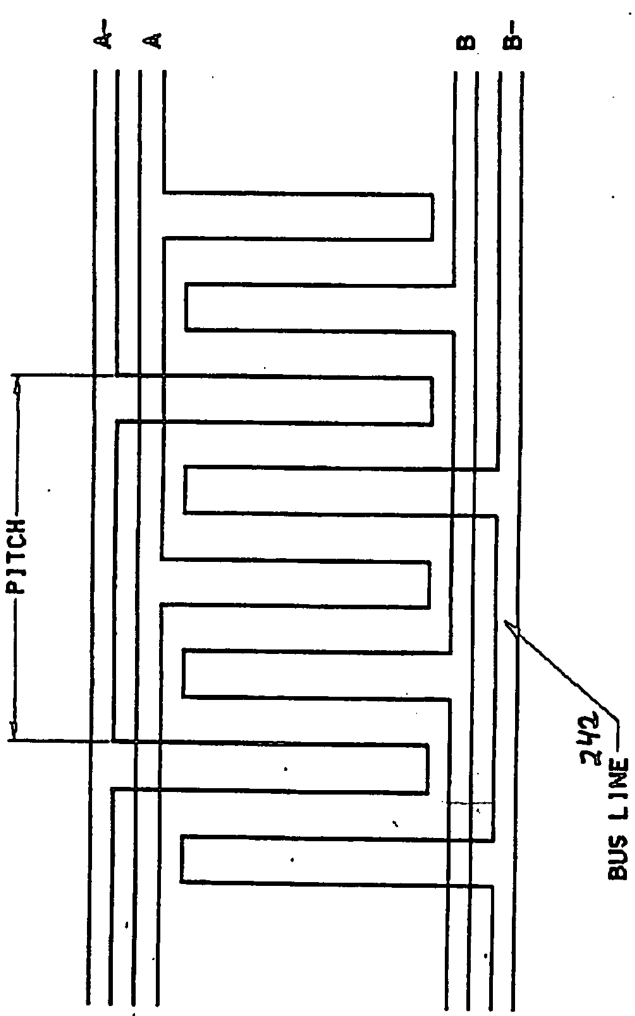


FIG. 7



B3

Fig. 8

INTER-DIGITATED PHOTODIODE DETECTOR ARRAY.

1. INDEX AND INDEX BAR DIODE ARRAYS HAVE THE SAME PATTERN PER PAGE 2 OF 3 FOR A GIVEN LINE COUNT.
2. ACTIVE AREAS ARE ANGULAR WITH RESPECT TO THE CENTER OF THE OPTICAL RADIUS.
3. 12 MICRON MAX SPACE DIVIDED EQUALLY BETWEEN ADJACENT DIODES.
4. AREAS DEFINED AS A, A-, B, B- ARE 1/2 CYCLE. ONE CYCLE IS 360° DIVIDED BY LINES PER REVOLUTION.

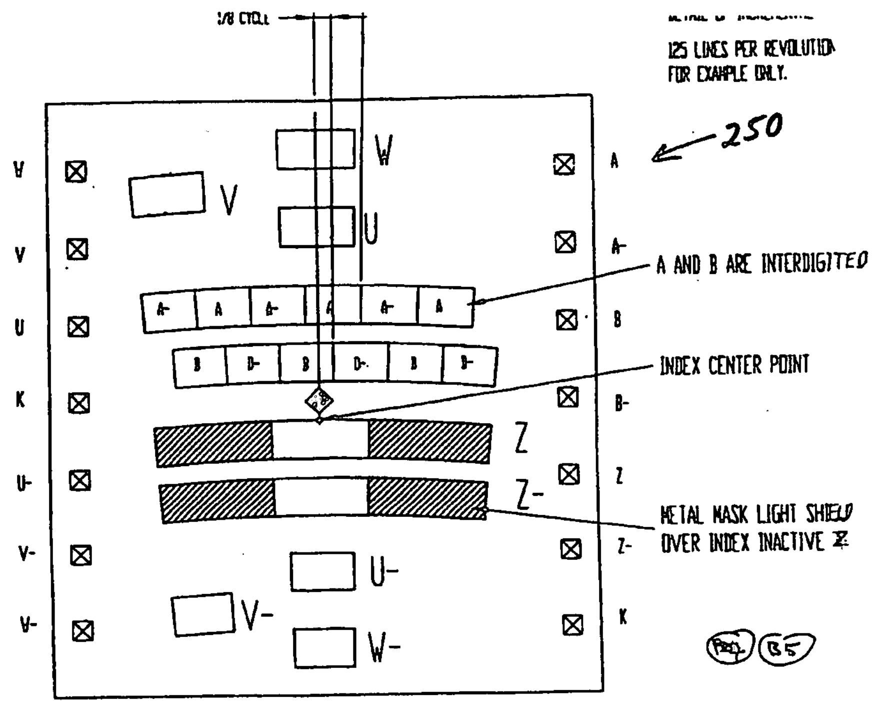


Fig. 10

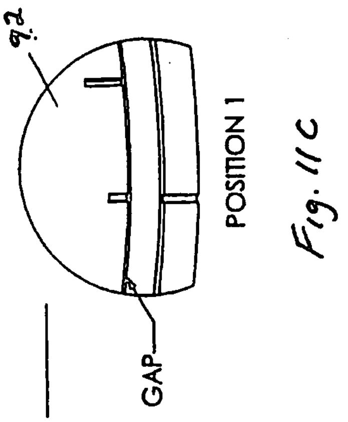


Fig. 11C

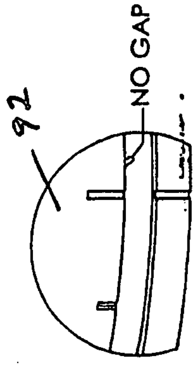


Fig. 11D

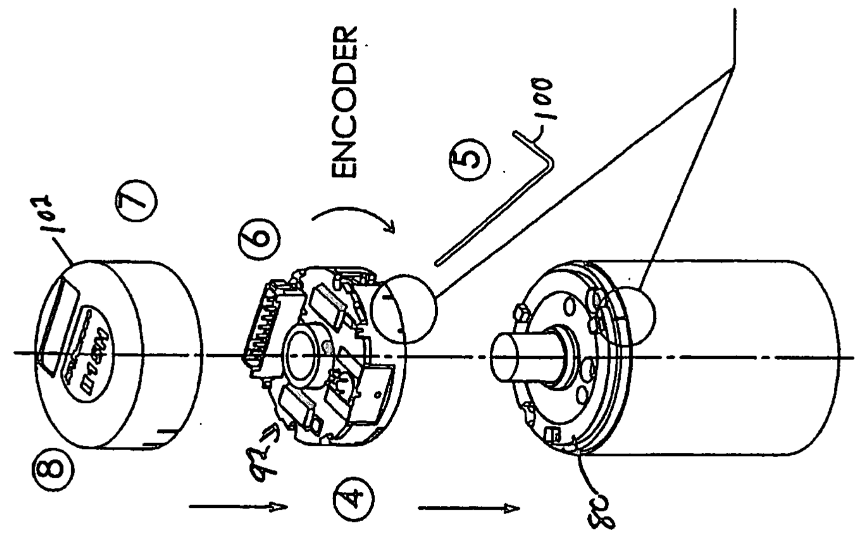


Fig. 11B

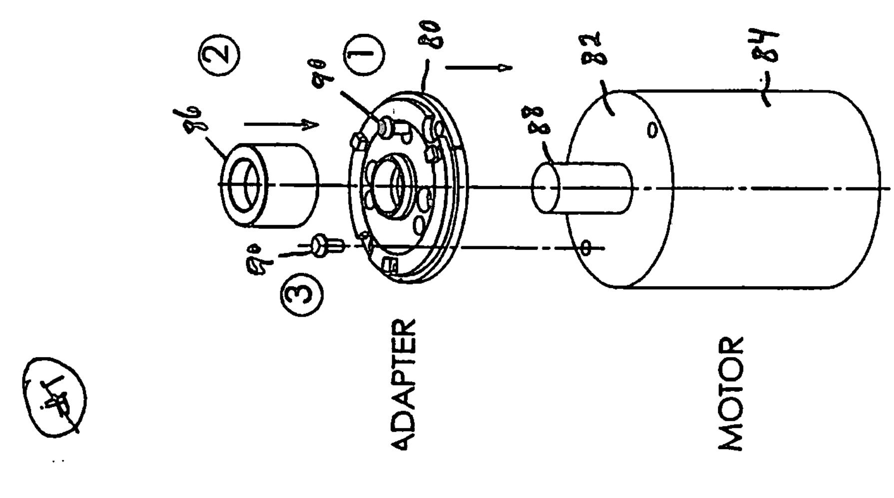


Fig. 11A

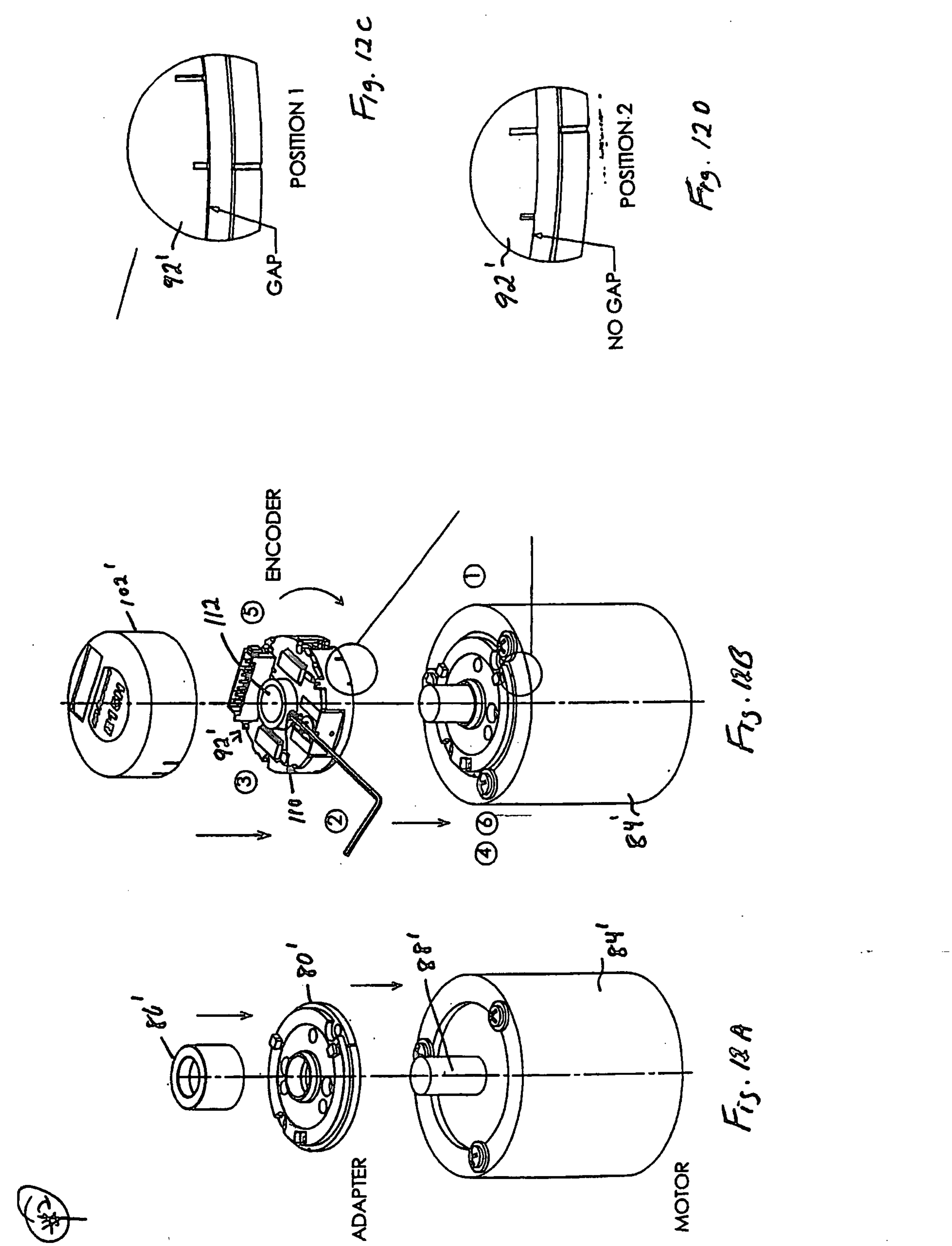


Fig. 12A

Fig. 12B

Fig. 12C

Fig. 12D

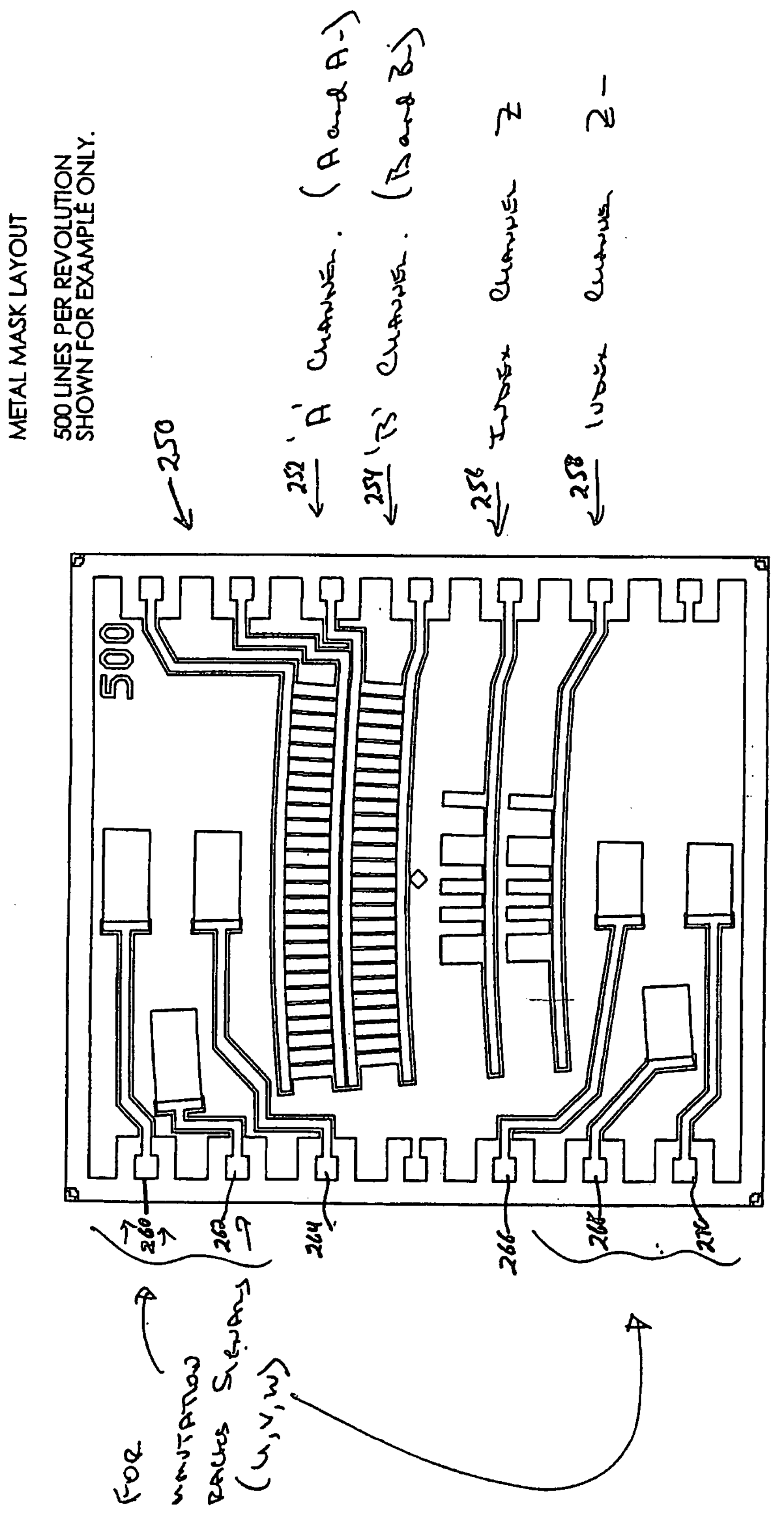

METAL MASK LAYOUT
500 LINES PER REVOLUTION
SHOWN FOR EXAMPLE ONLY.
250
252 'A' CHANNEL. (A and A-)
254 'B' CHANNEL. (B and B-)
256 INDEX CHANNEL Z
258 INDEX CHANNEL Z-
500
260
262
264
266
268
270
FOR COMMUTATION HALLS SENSORS (U, V, W)

Fig. 13

DEX·BAR DIODE ARRAYS HAVE THE SAME
:HEET 2 OF 4 FOR A GIVEN LINE COUNT.
: ARE ANGULAR WITH RESPECT TO
F THE OPTICAL RADIUS.
.AX SPACE DIVIDED EQUALLY BETWEEN
ODES.
D AS A, A-, B, B- ARE 1/2 CYCLE.
360° DIVIDED BY LINES PER REVOLUTION.

DETAIL OF INCREMENTAL TRACKS.

125 LINES PER REVOLUTION SHOWN
FOR EXAMPLE ONLY.

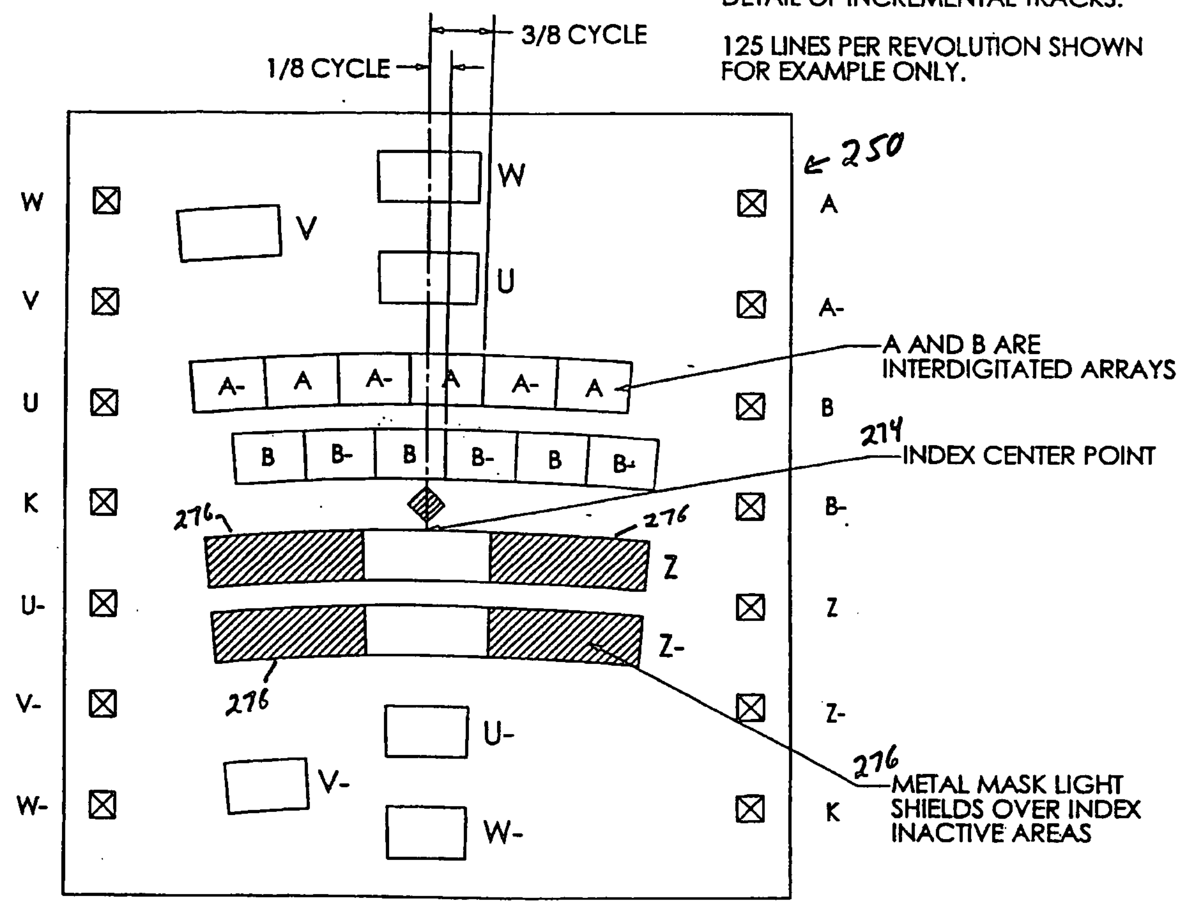


Fig. 14

PPED AS 4 INCH WAFER READY FOR BUMPING. NO INK MARKS.
)% VISUALLY INSPECTED AND PROBED. REJECTS MAPPED.
)T HAVE MORE THAN 20% REJECTS.
ED FOR DARK CURRENT AT ELEVATED TEMPERATURE OF 100°C.
; IS .020 INCHES.
: INDEX PATTERN.
: INCREMENTAL TRACK DESIGN GUIDE.
NCREMENTAL LINE COUNT. LOCATION AND SIZE OF ID IS OPTIONAL.

L CHARACTERISTICS

EMP COEFFICIENT	1.0%/C MAX (880 nm, 10 mW/sq cm)
DE LEAKAGE	100 nA MAX (300 mV)
AT 100°C (Id)	500 nA MAX (5 VDC, 100°C)
LTAGE (Vbr)	35 VDC MIN.
PONSE (-3db)	500 KHz MIN (1 μA CATHODE CURRENT, 880 nm)
NSITIVITY	880 nm TYPICAL
RITY	1% TYPICAL, 3% MAX
	0.3 A/W MIN (880 nm)

RATURE -55 TO 150°C IN FREE SPACE.
PERATURE -40 TO 125°C IN FREE SPACE.

1	LINE COUNT
	500
	512
	1000
	1024

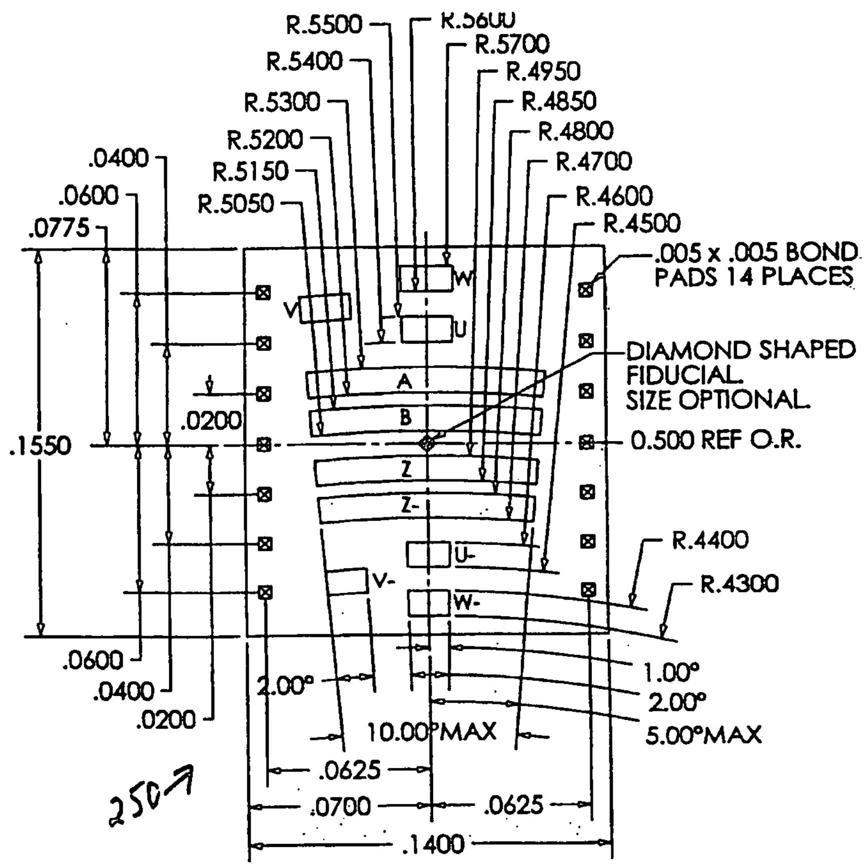
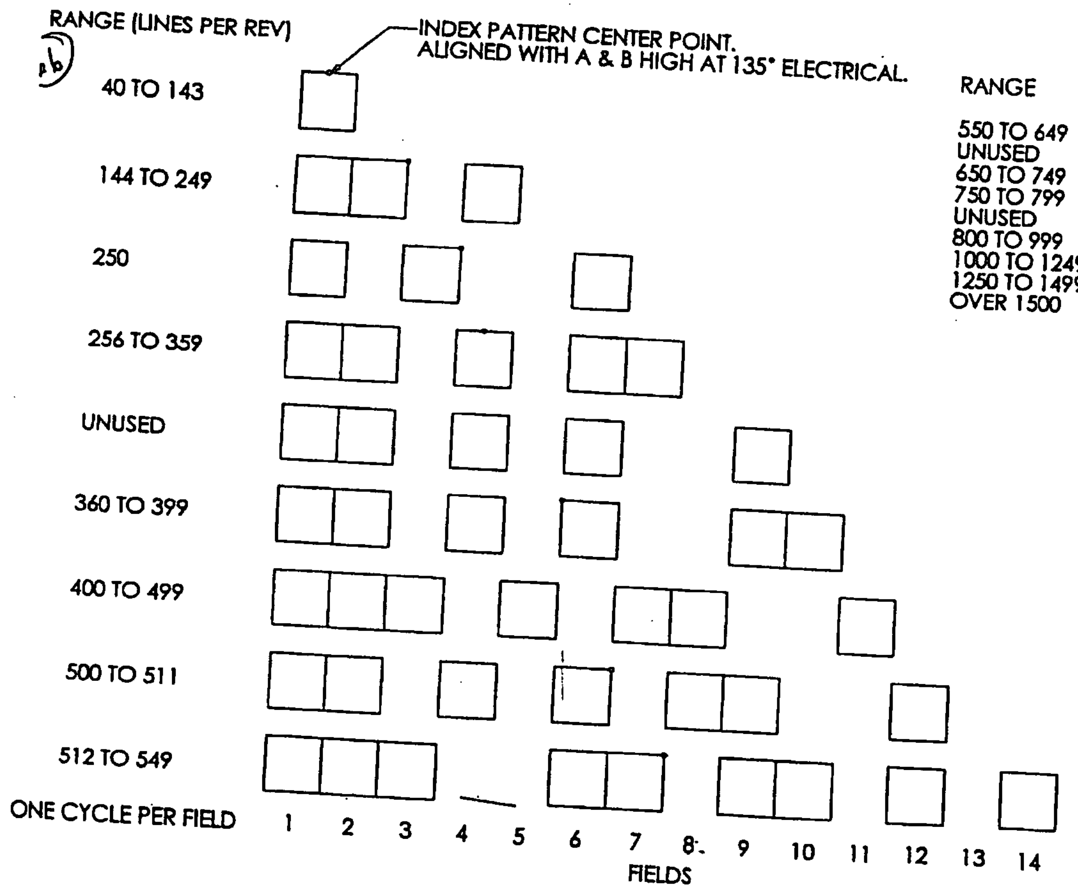


Fig. 15

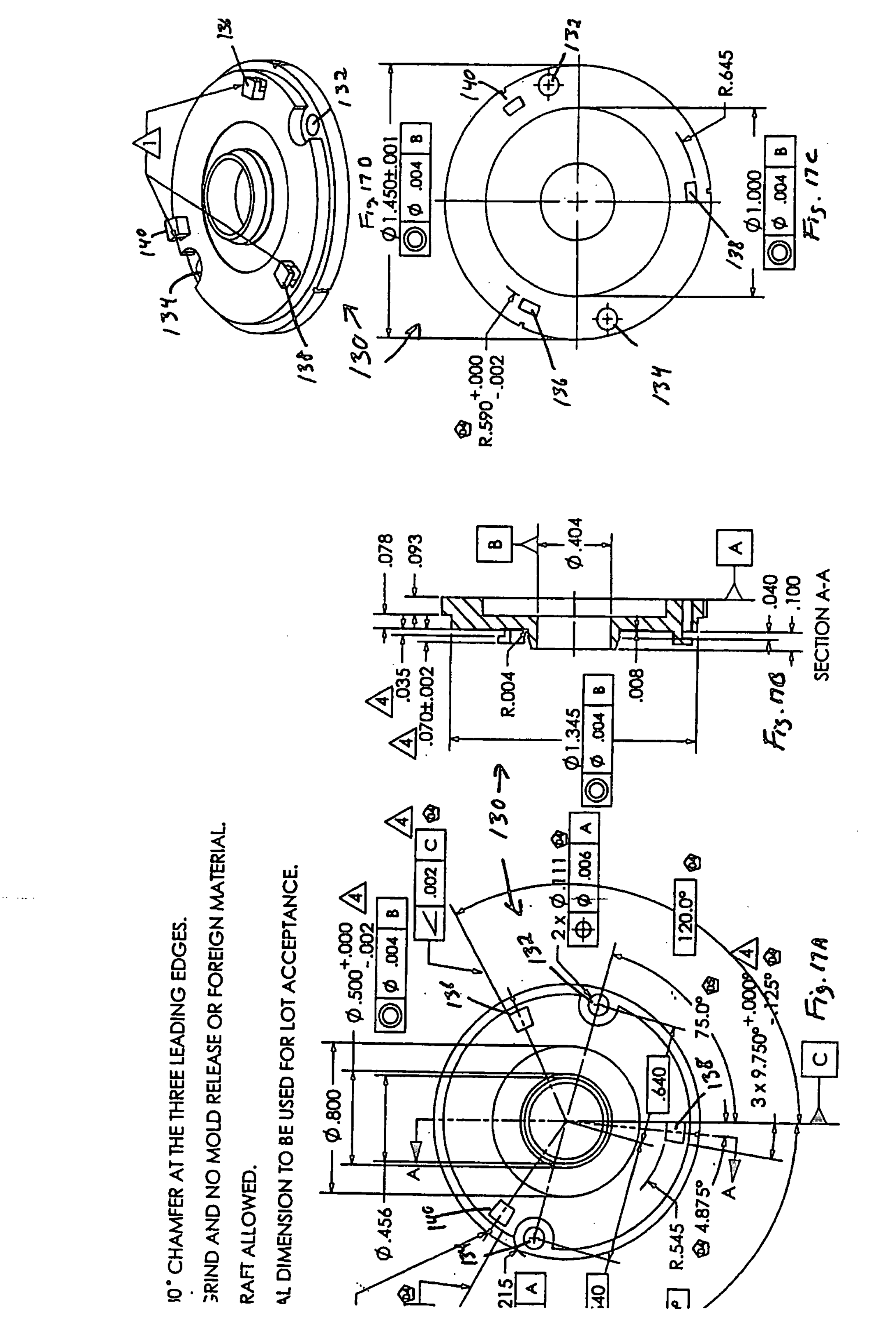


RANGE	PATTERN BY FIELD NUMBER	CENTER
550 TO 649	1-2-4-6-7-10-11-13-15	
UNUSED	1-2-3-6-7-9-10-12-14-16-17	8
650 TO 749	1-2-4-6-7-10-11-13-15-17-18	9
750 TO 799	1-2-4-6-7-10-11-13-15-17-20	9.5
UNUSED	1-2-3-6-7-8-10-13-14-16-17-19-21	10.5
800 TO 999	1-2-3-6-7-9-10-12-14-16-17-20-22	11
1000 TO 1249	1-2-4-6-7-10-11-13-15-17-18-21-23	11.5
1250 TO 1499	1-2-6-8-9-10-16-20-21-23-25-26-32-34	12
OVER 1500	1-2-5-7-8-10-16-17-18-21-25-28-29-30-36-3839-41-44-45	17.5
		23

Fig. 16

NOTES:

1. BLOCKED FIELD INDICATES ACTIVE AREA.
2. PATTERN SHOWN IS MIRRORED ON CODE DISK.
3. ONE INDEX FIELD IS 360° DIVIDED BY THE INCREMENTAL LINE COUNT.


SECTION A-A
Fig. 17A
Fig. 17B
Fig. 17C
Fig. 17D

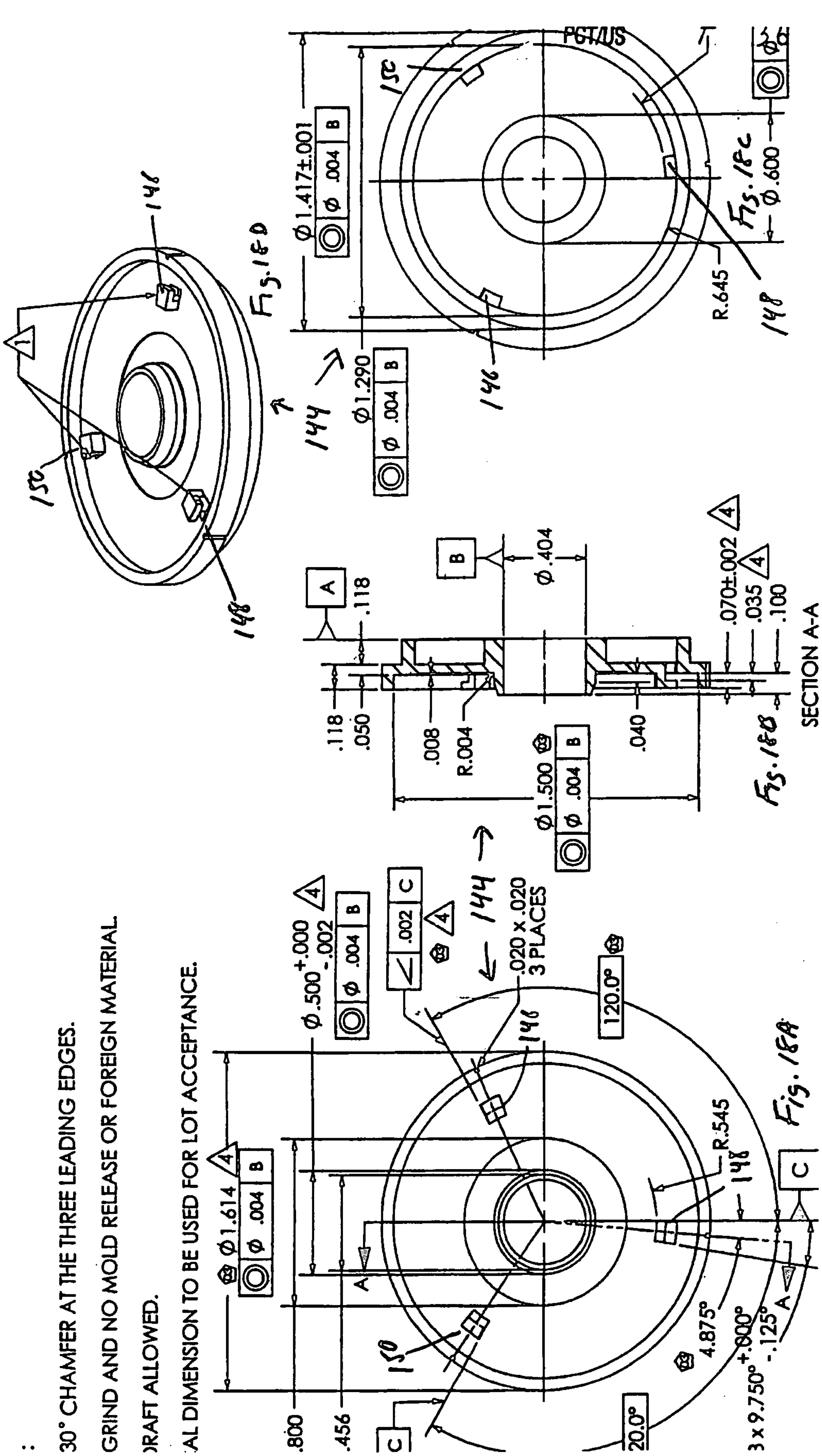
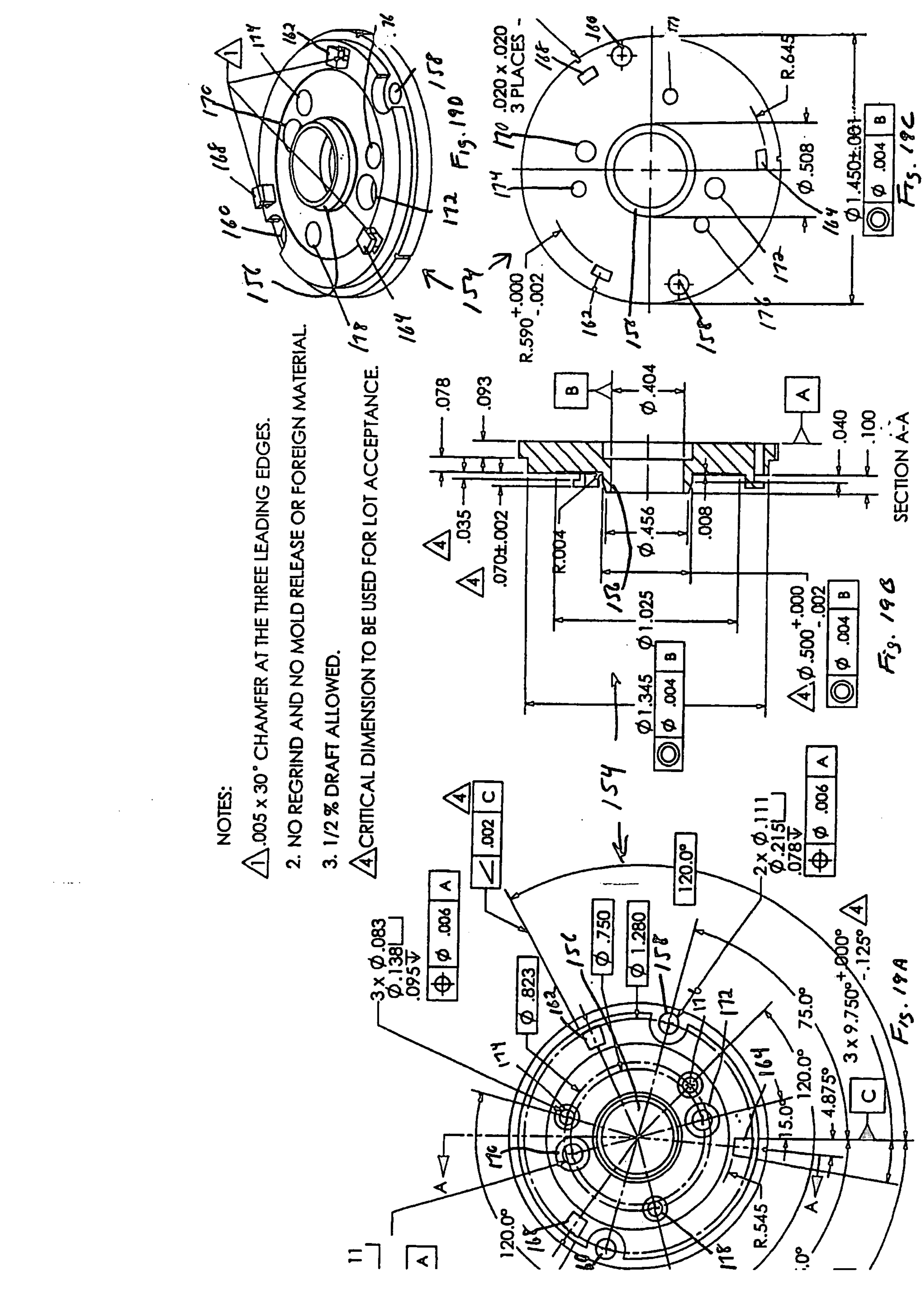


Fig. 18A

Fig. 18B

Fig. 18C

Fig. 18D


NOTES:
1. .005 x 30° CHAMFER AT THE THREE LEADING EDGES.
2. NO REGRIND AND NO MOLD RELEASE OR FOREIGN MATERIAL.
3. 1/2 % DRAFT ALLOWED.
4. CRITICAL DIMENSION TO BE USED FOR LOT ACCEPTANCE.
Fig. 19A
Fig. 19B
Fig. 19C
Fig. 19D
SECTION A-A
3 x Ø.083
2 x Ø.111
Ø .823
Ø .750
Ø 1.280
120.0°
75.0°
15.0°
4.875°
R.545
Ø 1.345
Ø 1.025
Ø .456
Ø .404
Ø .500
.070±.002
.035
.078
.093
.040
.100
.008
R.004
R.590
R.645
Ø .508
Ø 1.450±.001
.020 x .020
3 PLACES

·TES:

5 x 30° CHAMFER AT THE THREE LEADING EDGES.

GRIND AND NO MOLD RELEASE OR FOREIGN MATERIAL.

% DRAFT ALLOWED.

ITICAL DIMENSION TO BE USED FOR LOT ACCEPTANCE.

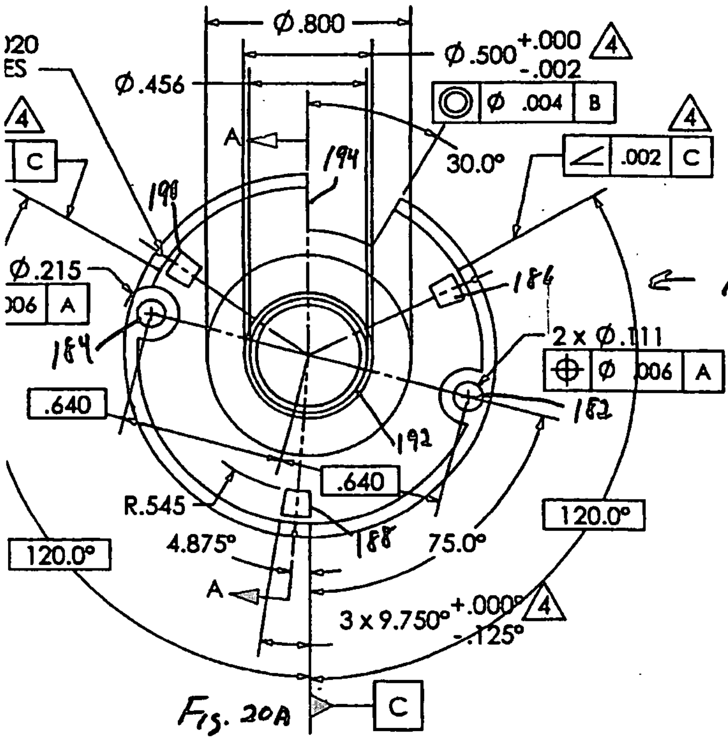


Fig. 20A

180

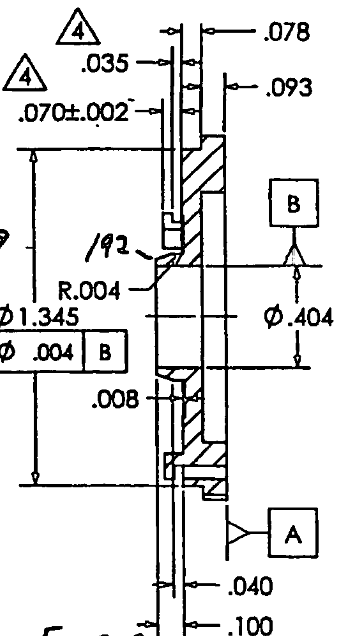


Fig. 20B
SECTION A-A

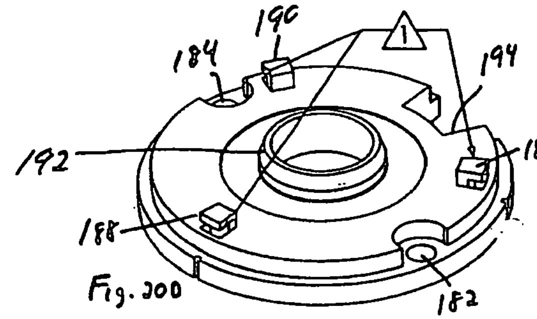


Fig. 20D

180

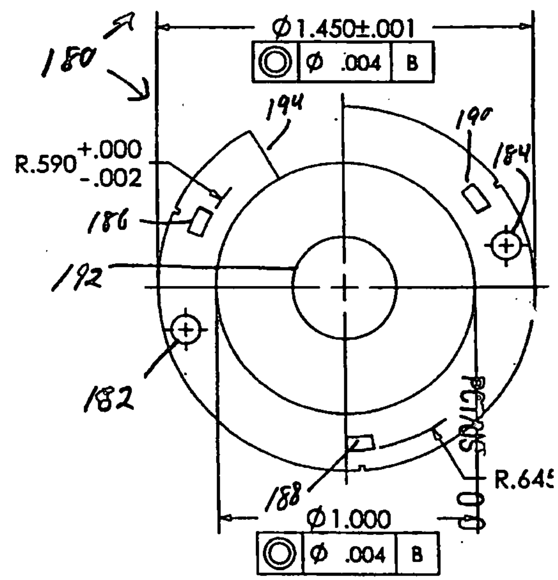
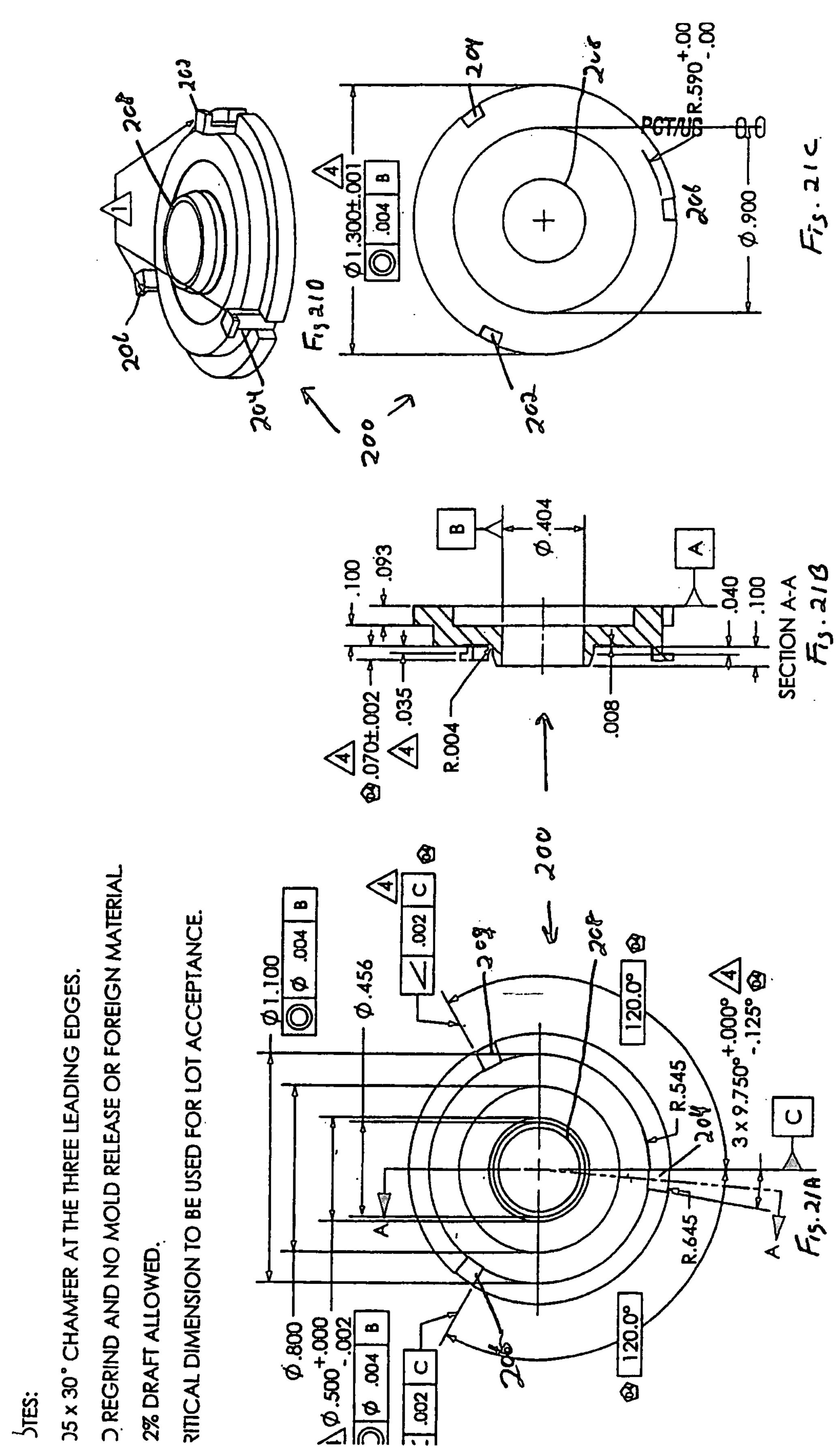


Fig. 20C


OTES:
05 x 30° CHAMFER AT THE THREE LEADING EDGES.
O REGRIND AND NO MOLD RELEASE OR FOREIGN MATERIAL
2% DRAFT ALLOWED.
RITICAL DIMENSION TO BE USED FOR LOT ACCEPTANCE.
Ø.800
Ø.500 +.000 -.002
Ø1.100
Ø.456
R.545
R.645
3 x 9.750° +.000° -.125°
120.0°
200
202
204
206
208
Fig. 21A
Ø.404
.100
.093
.070±.002
.035
R.004
.008
.040
.100
SECTION A-A
Fig. 21B
Ø1.300±.001
Ø.900
R.590 +.00 -.00
Fig. 21C
Fig. 21D

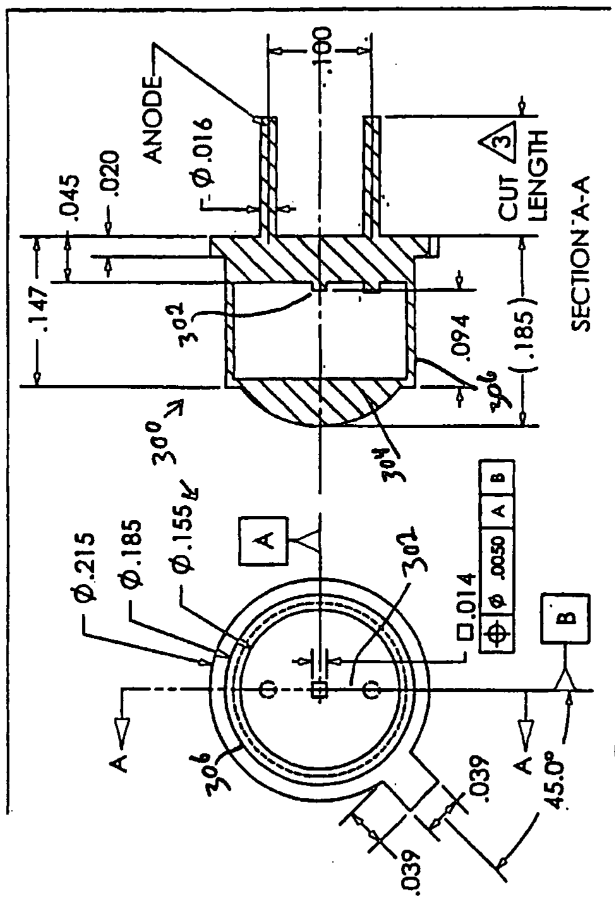


Fig. 22B

Fig. 22A

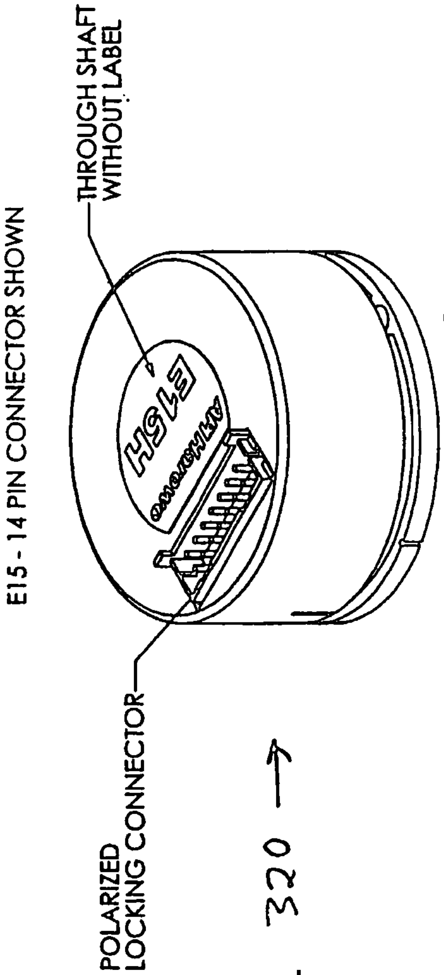


Fig. 23B

320

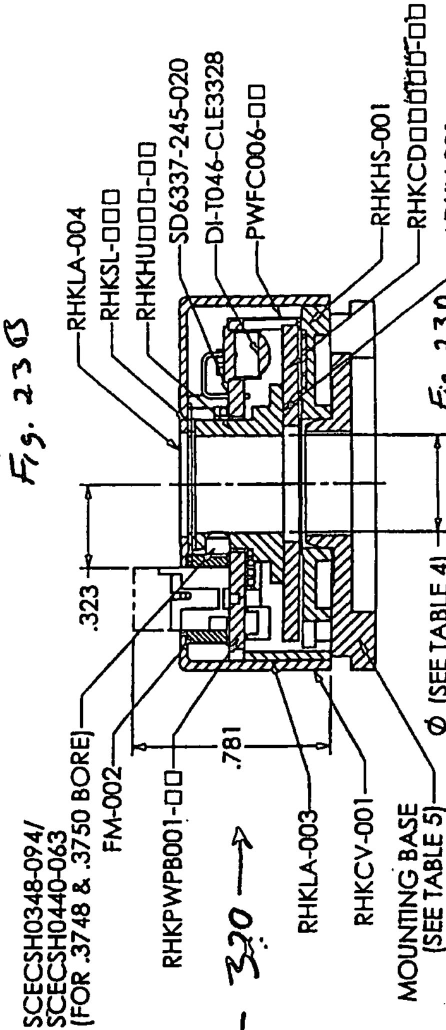


Fig. 23D

320

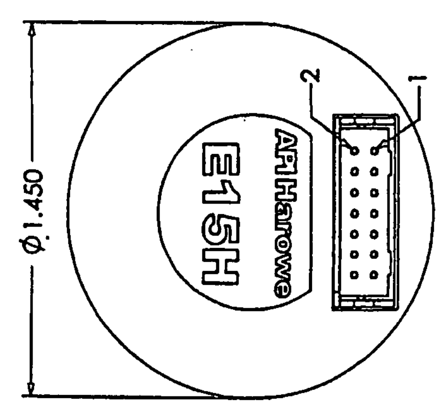


Fig. 23A

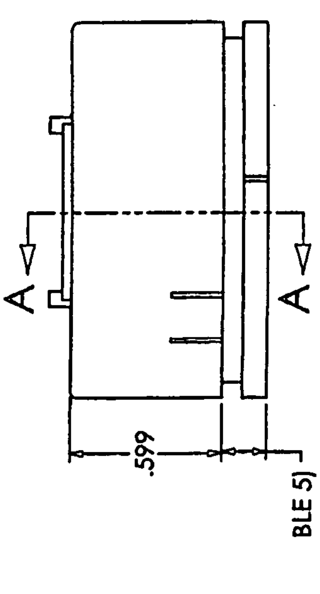
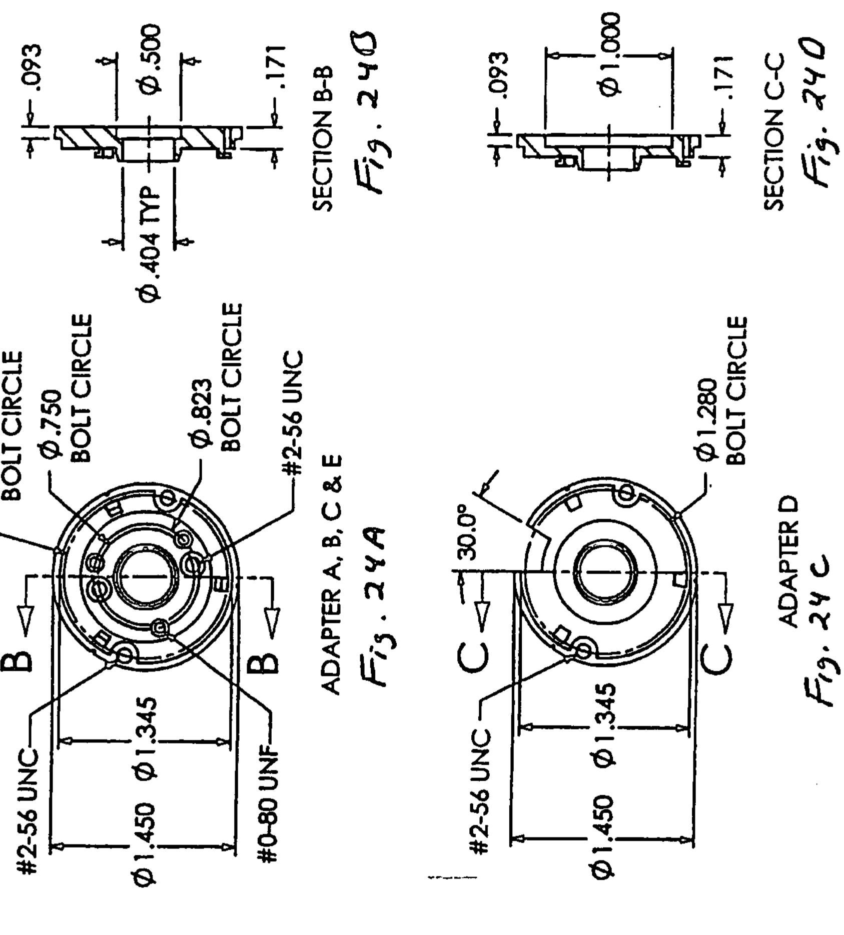


Fig. 23C



ADAPTER A, B, C & E
Fig. 24A

Fig. 24B

ADAPTER D
Fig. 24C

Fig. 24D

315

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US00/24368

A. CLASSIFICATION OF SUBJECT MATTER
IPC(7) :G01D 5/347
US CL :250/231.14, 231.16
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
U.S. : 250/231.14, 231.16, 231.13, 231.15, 231.17, 231.18

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
NONE

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
NONE

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 4,338,517 A (PERRINE) 06 July 1982 (06.07.1982), see entire document.	1-6
A	US 4,899,048 A (SHELANDER) 06 February 1990 (06.02.1990), see entire document.	1-6
A	US 5,841,132 A (HORTON et al) 24 November 1998 (24.11.1998), see entire document.	1-6

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier document published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
18 NOVEMBER 2000	08 JAN 2001
Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231 Facsimile No. (703) 305-3230	Authorized officer JOHN LEE Telephone No. (703) 308-0956 Renee Paxton

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